Utilizing Ultrasound Elastography to Examine the Material Properties of the Interosseous Membrane

by

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A Senior Honors Project Presented to the

Honors College

East Carolina University

In Partial Fulfillment of the

Requirements for

Graduation with Honors

by

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April 2018

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Abstract:

The involvement of the distal radio-ulnar joint (DRUJ) in a combination of high and low impact activities can lead to a variety of injuries. Previous studies done on cadavers have revealed that the distal interosseous membrane (DIOM) plays a role in stability of the DRUJ. Evidence from previous studies shows that thickness, stiffness, and length of the DIOM vary substantially on an individual basis. The "central band region," is the most universally similar region and of particular interest in regards to wrist stability in extension. Chronic extension of the wrist has been shown to affect this membrane and lead to injury and instability of the DRUJ. Without proper healing, changes in the wrist to elbow load and forearm rotation mechanisms are compromised.

Recently, ultrasound is being used to explore the ligament anatomy of the wrist because it is a comparatively safe and inexpensive alternative to radiography. Developing a reliable methodology for examining this membrane with the specialized technique called shear-wave elastography will provide medical professionals and researchers alike with a cheaper, safer, and less invasive way to diagnose DRUJ instability and examine its healing potential.

The purpose of this study was to determine whether ultrasound elastography is a reliable way to measure the material properties of the interosseous membrane in a live population and to identify any trends that may affect the elastic properties of the membrane.

Nineteen subjects were brought into the lab on two occasions no more than a week apart. During both sessions, an ultrasound exam was performed on the participant’s right wrist and the images were used to obtain stiffness, thickness, and length values along the central band of the DIOM.

The Intraclass Correlation Coefficient for each variable indicated that the proposed methodology is a consistent and reliable way to examine the material properties of the DIOM in a live population. Additionally, gender appeared to have little to no effect on any of the variables. Whether or not an individual participates in regular weight training appears to have some effect on stiffness across the membrane.

Further research is needed to explain why the material properties vary for each individual, as well as the consequences of these differences.

Introduction

The distal half of the forearm joint, or human distal radio-ulnar joint (DRUJ), has evolved overtime from a simple block-like structure in four legged mammals to a complex articulation capable of intense load bearing and 160 degree rotation (Hagert & Hagert, 2010). It's involvement in a combination of high and low impact activities can lead to a variety of injuries including displaced fractures, dislocations, ligamentous tears, and other soft tissue trauma (Bancroft, 2013).

DRUJ instability is most commonly caused by direct trauma or overuse. The Triangular Fibro-Cartilaginous Complex, a group of ligaments that sit around this joint, give stability during movement of the forearm and wrist as it bends, flexes and rotates. If these ligaments become damaged, stretched or torn then the joint becomes loose and often leads to instability and dislocation of the DRUJ (Bancroft, 2013). Patients with DRUJ instability present with ulnar-sided wrist pain, swelling, and difficulty with gripping and forearm rotation (Bancroft, 2013).

Previous studies done on cadavers have revealed that the distal interosseous membrane (DIOM) plays a role in stability of the DRUJ (Okada et. al, 2014). The IOM is an important structure to consider in cases of elbow and forearm trauma; if injured, it can lead to longitudinal forearm instability (Rodriguez-Martin & Pretell-Mazzini, 2011). However, diagnosis of interosseous membrane injuries is challenging, and failure in diagnosis may result in poor clinical outcomes and complications (Rodriguez-Martin & Pretell-Mazzini, 2011).

Computed tomography and magnetic resonance imaging are both useful in the preoperative evaluation of the DIOM (Okada et. al, 2014). However, these methods are often avoided when diagnosing and evaluating DRUJ instability because of the associated cost and radiation exposure (Okada et. al, 2014). Recent technological progress has been made with the use of ultrasound, which is becoming increasingly preferred as a relatively safe and inexpensive alternative to radiography to explore ligament anatomy.

Previous studies utilizing ultrasound examination showed that the IOM was easily visualized as a highly echogenic structure, distinct from nearby muscles and lying between the shadows of the radius and ulna (Boardman et. al, 1996). The central band, or defined peak-like region, of the membrane can be seen in all individuals, despite individual variations such as differing fiber lengths and angle of origin at the radius (Boardman et. al, 1996). There are many other substantial individual variations that occur in the DIOM (Okada et. al, 2014). For example, greater DRUJ stability has been observed in individuals that possess a thick fibrous tissue known as the distal oblique bundle (DOB) (Okada et. al, 2014).

Supersonic shear-wave imaging is a new ultrasound-based technique for real-time visualization of soft tissue viscoelastic properties (Bercoff et. al, 2004). Ultrasonic focused beams create mechanical vibration sources that are able to radiate low-frequency, shear waves inside tissues (Bercoff et. al, 2004).

The ability to perform real-time dynamic high-resolution examinations makes ultrasound a very powerful diagnostic modality for the musculoskeletal system (Ryu & Jeong, 2017). Shear wave elastography is considered the most suitable type of ultrasound elastography for the musculoskeletal system, and is widely used for viewing tendons, ligaments, and muscles (Ryu & Jeong, 2017). Yet, no previous studies have utilized this technique to examine the material properties (thickness, stiffness, and length) of the DIOM. Few studies have looked at the membrane in a live population. Developing a reliable methodology for examining this membrane with the ultrasound elastography technique will provide medical professionals and researchers alike with a cheaper, safer, and less invasive way to diagnose DRUJ instability and examine its healing potential.

Purpose and Hypothesis

The purpose of this study was to determine whether the ultrasound technique known as shear-wave elastography is a reliable way to measure the material properties of the interosseous membrane in a live population and to identify any trends that may affect the elastic properties of the membrane.

We hypothesized that when measured using ultrasound elastography, thickness, stiffness, and length values for the membrane would remain consistent among an individual when measured on two different days. However, we expected the same variables would vary substantially across the members of the study population. We also expected that some common trends could be seen across the membrane based on gender. Finally, we believed that different material properties would be observed among individuals who indicate weight training as part of their regular exercise routine when compared to those who don't.

Methodology

Nineteen subjects (four male and fifteen female) were recruited for this study. Participants were required to be between the ages of 18-40, have no current wrist injury, and no history of wrist surgery to be included in the study.

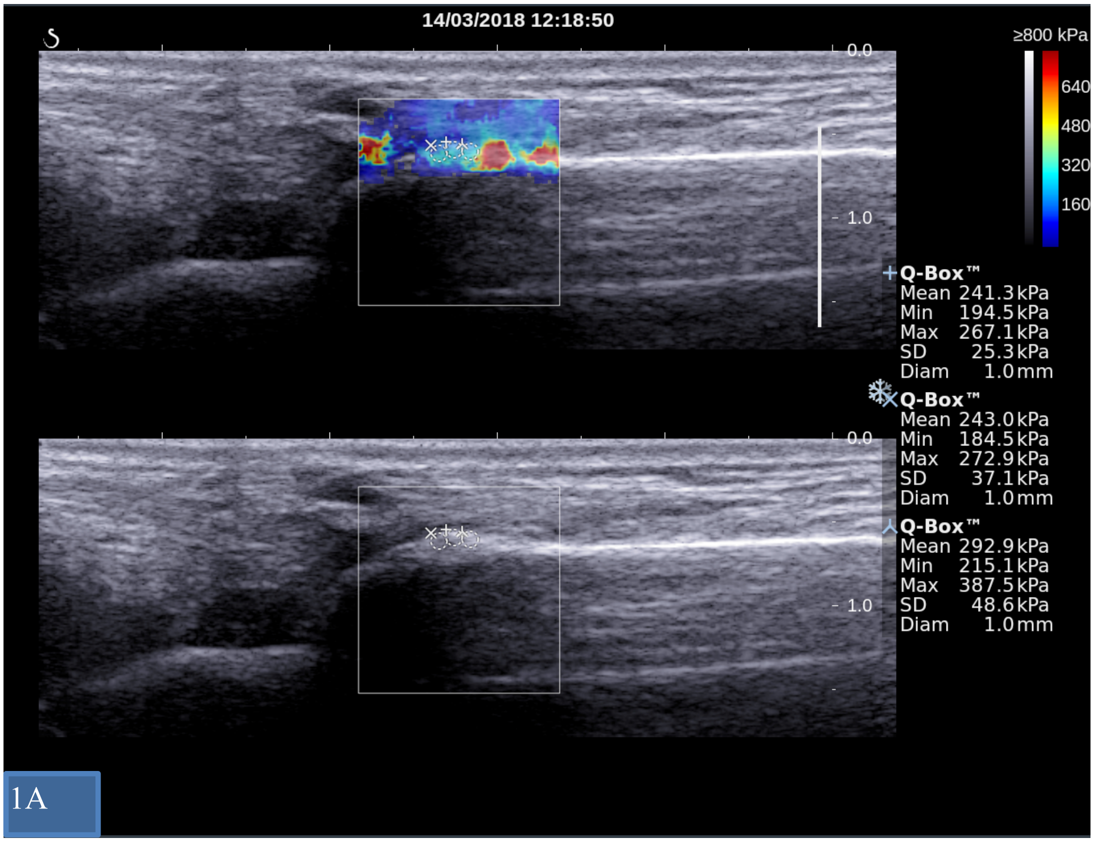
Participants were brought into the lab on two occasions no more than a week apart. During the first session, participants were asked to fill out a short open ended survey describing basic demographics, confirming a healthy wrist, and describing their physical activity in a typical week. Participants were categorized as "weight training" if they indicated participation in weight lifting activities or resistance training at least once during the week.

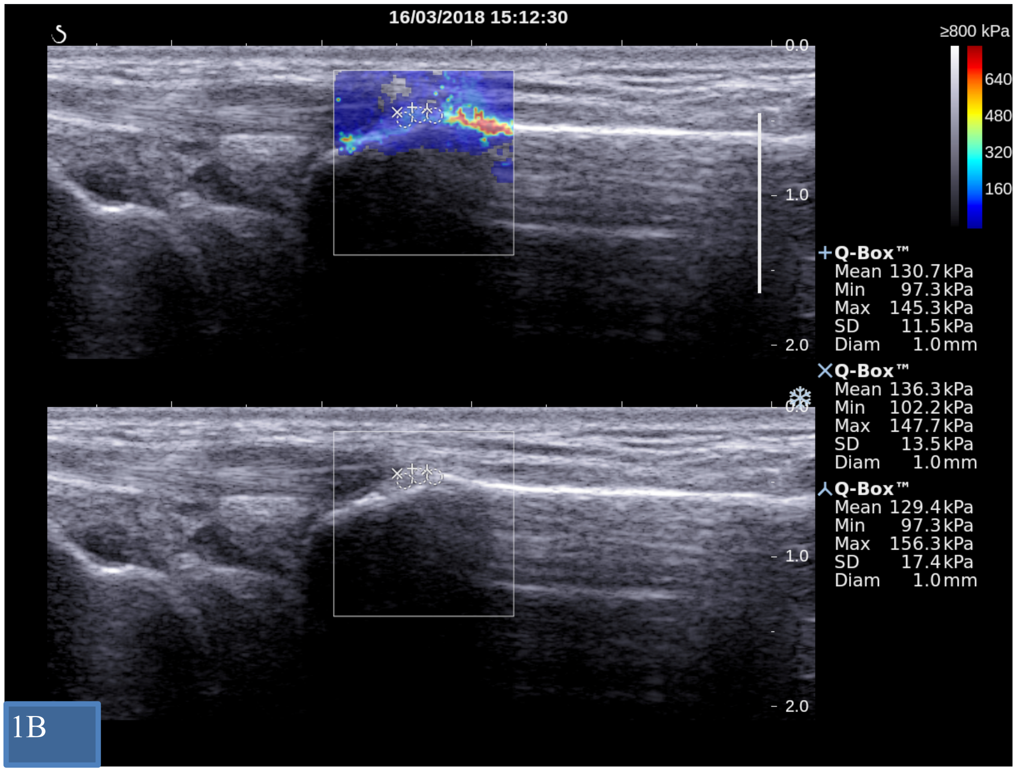
During both sessions, an ultrasound exam was performed on the participant's right wrist using the FDA approved Aixplorer SuperSonic Imagine. While taking images, the focal depth of the machine was always kept at 0.5 centimeters and probe held at an oblique angle between the patients radial and ulnar heads. Patients were asked to lie in a prone position with their wrist and forearm flat and level with their face. The wrist was kept stationary at a 30 degree angle of radial deviation. Three B-mode images were taken to obtain thickness and length values along the interosseous membrane. With shear-wave mode turned on and set to view stiffness up to 800 kPa, three more images were taken to obtain a stiffness value for the central band region.

Thickness was determined by measuring from top to bottom at the tallest point of the central band. Each subject's thickness measurement for the day was the average of the 3 B-mode images and recorded in centimeters. Length was determined by measuring from left to right across the entire peak region known as the central band. Each subject's length measurement for the day was recorded as the average of the three B-mode images and recorded in centimeters.

Within the three images using elastography, stiffness measurements were taken at three points along the membrane: the tallest point of the central band, and immediately to its left and right. Stiffness for each image taken was thus defined as the average of the three points in kilopascals. Each subject's stiffness measurement for the day was recorded as the average of the three images utilizing the elastography technique.

Results





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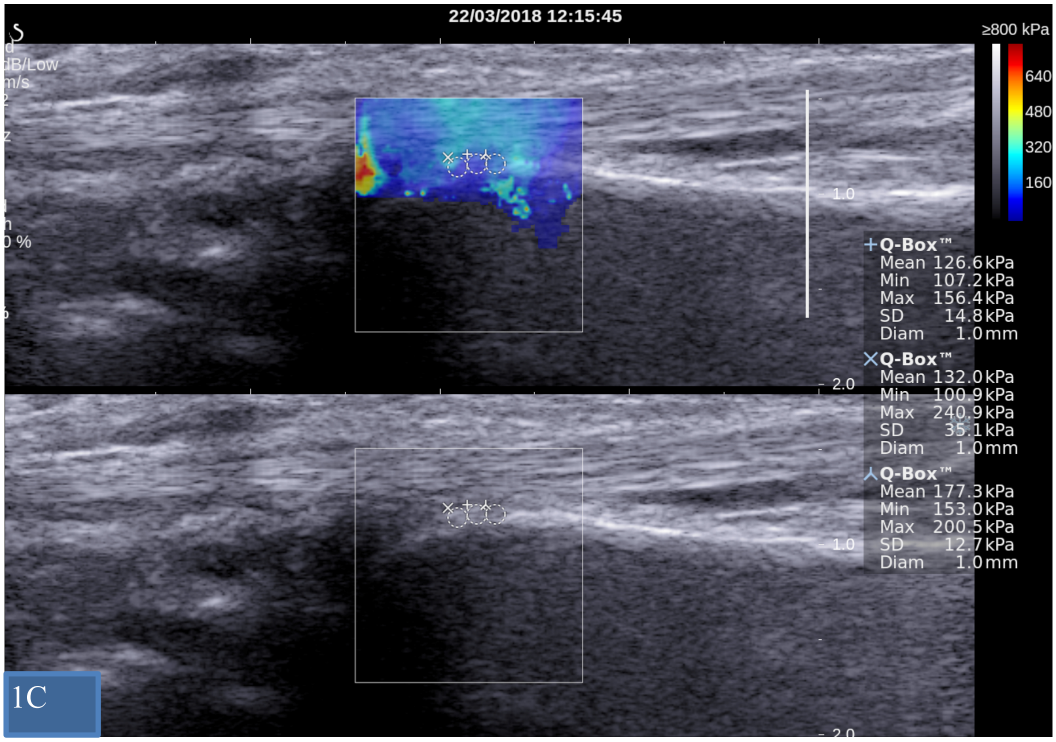
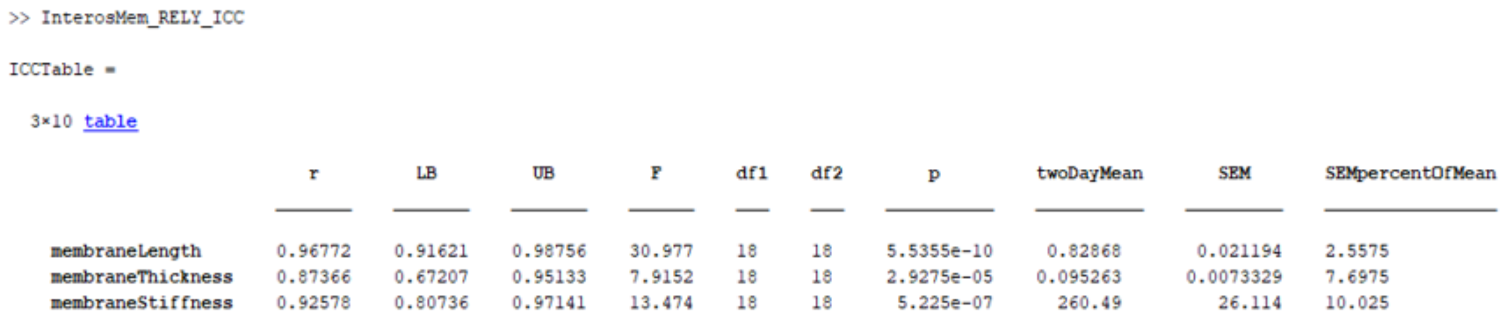


1C

<u>Fig 1:</u> The images above show several examples of the interosseous membrane taken using the shear-wave elastography method. Each of the three circles on the central band region is a point of stiffness being measured in kPa. Areas showing cooler colors such as blues and greens are less stiff, whereas areas that show up in the warmest oranges and reds possess a relatively high stiffness.



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  3×10 table

                           r          LB         UB          F       df1    df2         p          twoDayMean      SEM       SEMpercentOfMean
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    membraneLength      0.96772    0.91621    0.98756    30.977    18     18     5.5355e-10     0.82868      0.021194     2.5575
    membraneThickness   0.87366    0.67207    0.95133    7.9152    18     18     2.9275e-05    0.095263     0.0073329     7.6975
    membraneStiffness   0.92578    0.80736    0.97141    13.474    18     18      5.225e-07      260.49        26.114     10.025
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Fig 2: *The Intraclass Correlation Coefficient (ICC) is a statistical measurement used to describe how strongly units in the same group resemble each other. It is commonly used to assess consistency or reproducibility of quantitative measurements. The ICC for each of the three variables is shown above.*

	Length	**Thickness**	**Stiffness**
Max Range Per Subject Between Day 1 and Day 2	0.08 cm	0.03 cm	127.72 kPa
Avg Range Among Subject Values Between Day 1 and Day 2	0.04 cm s=0.02 cm	0.01 cm s=0.01 cm	38.93 kPa s=33.17 kPa
Range Across Population	0.59 cm	0.08 cm	302.45 kPa
Average Across Population	0.83 cm s= 0.12 cm	0.10 cm s=0.02 cm	259.3 kPa s=91.1 kPa

Table 1: *Statistics run on each variable show how each subject's measurements varied from the first day measured to the second, as well as the range and average across the population of the nineteen subjects.*

As seen in *Table One*, the maximum range per subject between day one and day two for each variable is defined as the maximum that any one subject's measurements changed between the two days observed. No subject showed a change in length greater than 0.08 cm, thickness greater than 0.03 cm, or stiffness greater than 127.72 kPa, between the two days measured.

The average range across subjects is the average of all of the nineteen subject's ranges between the day one and two measurements. Each subject's measurement between day one and day two varied by an average of 0.04 cm for length (s=0.02 cm), 0.01 cm for thickness (s=0.01 cm), and 38.93 kPa for stiffness (s=33.17).

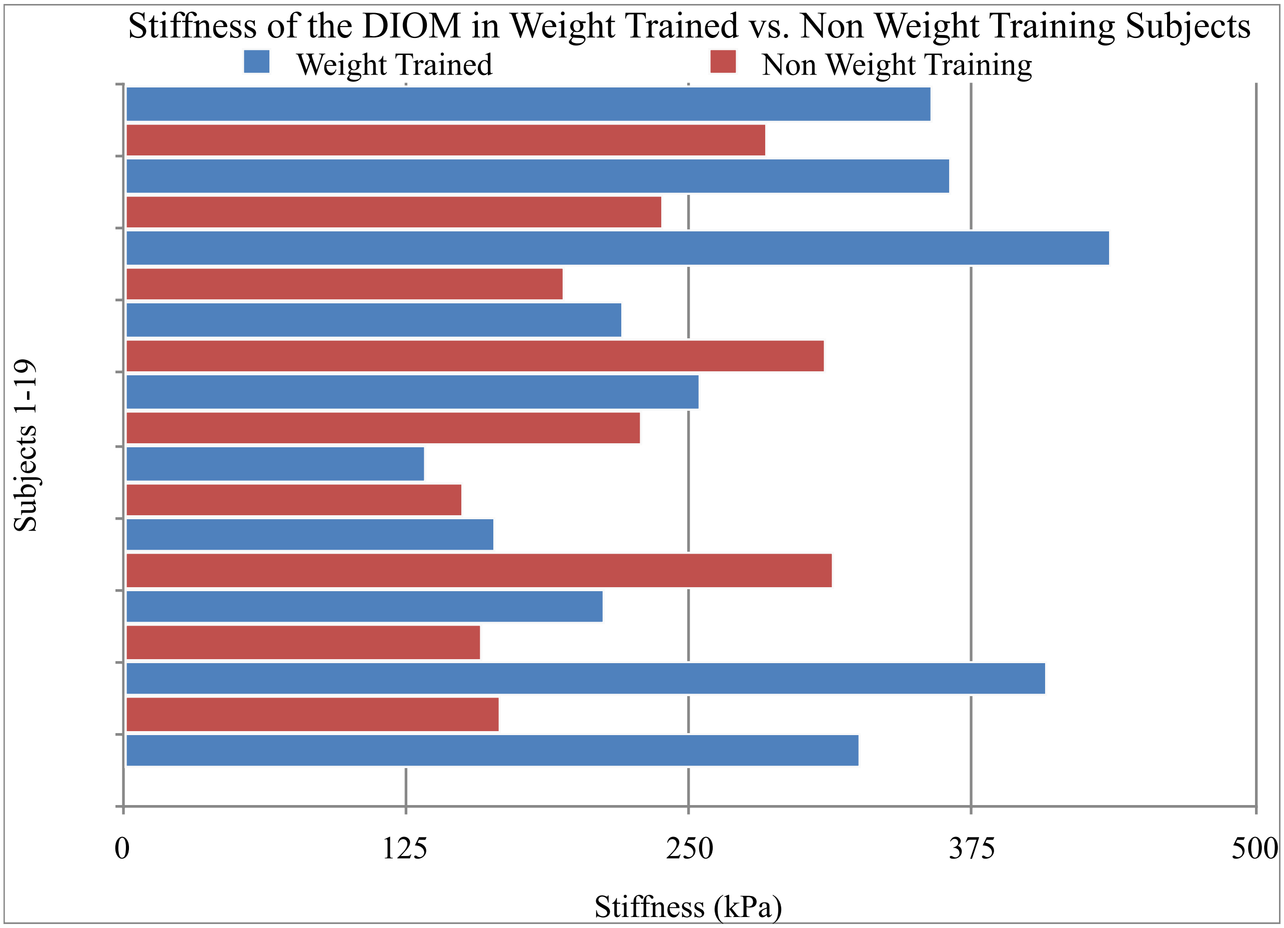
The range across the population was greater for each variable, indicating that the material properties differ greatly from one individual subject's membrane to the next. Stiffness varied the most across the subjects, with a population range of 302.45 kPa. The maximum range across population members for thickness and length was 0.59 cm and 0.08 cm respectively.

The average length of the distal interosseous membrane central band across the entire population was 0.83 cm (s=0.12 cm). The average thickness value across the entire population was 0.10 cm (s=0.02 cm). The average stiffness value across the population was 259.3 kPa (s=91.1 kPa).

	Length	**Thickness**	**Stiffness**
Male Subjects	0.83 cm s= 0.05 cm	0.08 cm s= 0.02 cm	301.24 kPa s= 50.48 kPa
Female Subjects	0.83 cm s=0.13 cm	0.10 cm s=0.02 cm	248.14 kPa s=93.2 kPa

Table 2: Four males and fifteen females took part in this study. The table shows the mean values calculated for each of the three elastic property variables grouped by gender.

The mean length for the DIOM was 0.83 cm for both the male and female groups. The mean thickness of the DIOM of males participating in the study was 0.08 cm (s=0.02 cm); for females the mean thickness was 0.10 cm (s=0.02 cm). The mean stiffness across the DIOM for the male group was 301.24 kPa (s=50.48), while it was 248.14 kPa (s=93.2 kPa) for the females.



<u>Fig 3:</u> The bar graph shows the average stiffness value for each subject across two days. Non-weight training subjects (red) typically presented a less stiff membrane than weight trained subjects (blue).

Figure Three presents the average stiffness values for each subject, including both days they were measured. Ten subjects self-reported participation in weight training activities during the average week and were classified as weight trained. The nine remaining subjects did not indicate weight training as part of their regular exercise routine and were thus classified as non-weight training. In general, the subjects indicating weight training demonstrated a greater stiffness across their interosseous membrane than those who didn't. The mean stiffness value for weight training subjects was 287.91 kPa (s= 99.5 kPa); the mean stiffness value for those who didn't regularly weight train was 227.54 kPa (s= 60.63 kPa).

Discussion

Wrist injuries are increasingly common. Unfortunately, why they occur and the ways in which they heal are only fairly understood. The precise mechanism of load transfer from wrist to elbow is one area that needs greater focus (Markolf et. al, 2000). The mechanical role of the interosseous membrane in this mechanism is complicated and remains unclear (Markolf et. al, 2000).

However, there is great evidence supporting the role of the DIOM in providing support and stability to the DRUJ. Understanding the types of individual variations that occur in the DIOM may provide insight into wrist injury mechanisms and allow injuries to be spotted before they occur.

CT and MRI scans are typically avoided when diagnosing and evaluating DRUJ instability because of the associated cost and radiation exposure (Okada et. al, 2014). Thus it is necessary to start using the technological advances made regarding ultrasound machines to assess wrist ligament damage. Length and thickness of the DIOM can easily be visualized on an ultrasound B-mode image. The more specialized technique, shear-wave elastography, is particularly adept at measuring stiffness in most muscles, tendons, and ligaments. Discovering a reliable methodology for examining this membrane using shear wave elastography makes for a safer, faster, and cheaper way to diagnose wrist injury and trauma.

The results of this experiment showed consistent measurements among nineteen subjects across two days. The ultrasound machine was successfully utilized to measure the elastic properties of thickness, stiffness, and length. The Intraclass Correlation Coefficients for all three variables showed strong consistency between each subject’s measurements, thus strong reliability of the proposed methodology.

The variables of thickness and length were fairly consistent across the population. It was stiffness that varied most greatly from one individual to the next. Some factors that might affect the elastic properties of the membrane were briefly explored in this experiment.

Gender did not appear to affect the thickness or length of the membrane significantly. The group of male participants did show a greater stiffness on average than females by about 50 kPa. However, it must be noted that the group of female participants was about four times greater than that of the males. Future experiments should assess a population in equal in male and female participants in order to be able to state a conclusion about the effects of gender on the stiffness in the DIOM.

Regular participation in weight training activities did not appear to have an effect on the length or thickness of the DIOM. However, regular weight training does appear to have some effect on the stiffness of the DIOM. The mean stiffness value was greater in those subjects classified as weight trained. The subjects with the highest membrane stiffness observed were those who indicated weight training. This is important because it shows the technique is sensitive enough to measure expected changes.

A reliable methodology to study this membrane in a live population opens a flood gate of questions. It is now understood that these properties vary among individuals but the reasoning why has not been determined. Future work should explore the types of weight training that affect the membrane, as well as how the DIOM changes with age, over the course of a training program, and in special populations. Other areas of exploration could include determining the sensitivity and specificity of shear wave elastography for diagnosis of a DIOM injury and to examine the IOM of the lower leg.

Each new insight will lead us to an understanding of wrist injury mechanisms and the healing potential of the DIOM.

Limitations

This study examined the DIOM in subjects aged 18-40. All participants were younger than 25. Findings may not translate to a younger or older population.

The study population consisted of four males and fifteen females. Future studies exploring the role that gender plays regarding the properties of the DIOM should use a population more equally distributed. A larger population in general would also strengthen the claims made in this study.

It is to be noted that participants were asked about their exercise open-endedly. Subjects self reporting their physical activity may have different definitions of weight training than those conducting the research. In future work, strict protocol should be used to define the type and frequency of weight training in order to avoid error when classifying subjects. An intervention program could also be used during the course of the experiment to see if stiffness will increase as the intervention progresses.

Conclusion

The results of our study demonstrated that shear wave elastography is a reliable way to measure the material properties of the interosseous membrane in a live population.

Thickness, stiffness, and length values for the membrane remain consistent among an individual when measured on different days. However, different material properties can be observed among the population. The technique is sensitive enough to measure expected changes in regards to a weight training program.

Further research is needed to explain why these material properties are different for each individual, as well as the consequences of these differences. Each new insight will lead us to an understanding of wrist injury mechanisms and the healing potential of the DIOM.

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East Carolina University

Informed Consent to Participate in Research

Information to consider before taking part in research that has no more than minimal risk.

Title of Research Study: Using Elastography to Examine Material Properties of the Interosseous Membrane

Principal Investigator: Dr. Zac Domire
Department: East Carolina University Department of Kinesiology
Address: 332-A Ward Sports Medicine Building, East Carolina University, Greenville, NC 27858
Telephone #: (252) 737-4564
Study Coordinator: Ashley Kubit
Telephone #: (910) 366-2919

Researchers at East Carolina University (ECU) study issues related to society, health problems, environmental problems, behavior problems and the human condition. To do this, we need the help of volunteers who are willing to take part in research.

Why am I being invited to take part in this research?

The purpose of this research is to determine whether ultrasound elastography is a valid and reliable way to evaluate the properties of the forearm's interosseous membrane. You are being invited to take part in this research because you are a healthy individual aged 18-40 with no current wrist injury or former wrist surgery. The decision to take part in this research is yours to make. This structure is frequently injured and is difficult to diagnose. By doing this research, we hope to learn whether or not ultrasound elastography can be used in future studies involving this membrane to determine it's clinical potential.

If you volunteer to take part in this research, you will be one of about 20 people to do so.

Are there reasons I should not take part in this research?

I understand I should not volunteer for this study if I am under 18 years of age, above 40 years of age, possess a current injury to the wrist or forearm, and/or have undergone surgery to the wrist or forearm.

What other choices do I have if I do not take part in this research?

You can choose not to participate.

Where is the research going to take place and how long will it last?

The research will be conducted at the Wards Sport Medicine Building of East Carolina University. You will need to come to the Biomechanics Laboratory on the third floor twice times during the study. The total amount of time you will be asked to volunteer for this study is approximately 30 minutes each day on two separate occasions no more than a week apart.

What will I be asked to do?

On two separate occasions, you will be asked to come to the Biomechanics lab on the third floor of East Carolina University's Ward Sports Medicine Building. You will be asked to lay face down on an examination table with one forearm bent and extended upwards. You will be required to stay still while a member of the research team will perform an ultrasound examination on your right forearm. The exam will allow study members to collect data on the thickness, stiffness, and length of your interosseous membrane. This process will take approximately 30 minutes each time.

What might I experience if I take part in the research?

We don't know of any risks (the chance of harm) associated with this research. Any risks that may occur with this research are no more than what you would experience in everyday life. We don't know if you will benefit from taking part in this study. There may not be any personal benefit to you but the information gained by doing this research may help others in the future.

Will I be paid for taking part in this research?

We will not be able to pay you for the time you volunteer while being in this study.

Will it cost me to take part in this research?

It will not cost you any money to be part of the research.

Who will know that I took part in this research and learn personal information about me?

ECU and the people and organizations listed below may know that you took part in this research and may see information about you that is normally kept private. With your permission, these people may use your private information to do this research:

- Any agency of the federal, state, or local government that regulates human research. This includes the Department of Health and Human Services (DHHS), the North Carolina Department of Health, and the Office for Human Research Protections.
- The University & Medical Center Institutional Review Board (UMCIRB) and its staff have responsibility for overseeing your welfare during this research and may need to see research records that identify you.

How will you keep the information you collect about me secure? How long will you keep it?

All data and identifying information will only be kept until the completion of the study. Participants' names will not be released to anyone else. Data will be coded in encrypted spreadsheets, housed on a password-protected, secure computer in Ward Sports Medicine Building in room 332. Participants' names will not be published, revealed in papers, abstracts, or in any other form. Should there be any paper copies with participants' data on it, these will be stored in a locked file cabinet in Ward Sports Medicine Building Room 332A until the end of the study. The papers will then be destroyed.

What if I decide I don't want to continue in this research?

You can stop at any time after it has already started. There will be no consequences if you stop and you will not be criticized. You will not lose any benefits that you normally receive.

Who should I contact if I have questions?

The people conducting this study will be able to answer any questions concerning this research, now or in the future. You may contact the Principal Investigator at (252) 737-4564 weekdays, between 8 AM-5 PM.

If you have questions about your rights as someone taking part in research, you may call the Office of Research Integrity & Compliance (ORIC) at phone number 252-744-2914 (weekdays, 8:00 am-5:00 pm). If you would like to report a complaint or concern about this research study, you may call the Director of the ORIC, at 252-744-1971.

Are there any Conflicts of Interest I should know about?

There are no conflicts of interest regarding this study.

I have decided I want to take part in this research. What should I do now?

The person obtaining informed consent will ask you to read the following and if you agree, you should sign this form:

- I have read (or had read to me) all of the above information.
- I have had an opportunity to ask questions about things in this research I did not understand and have received satisfactory answers.
- I know that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

____

Participant's Name (PRINT) **Signature** **Date**

Person Obtaining Informed Consent: I have conducted the initial informed consent process. I have orally reviewed the contents of the consent document with the person who has signed above, and answered all of the person's questions about the research.

____

Person Obtaining Consent (PRINT) **Signature** **Date**